Investigations on Wear by Slurry Abrasion of Hardfaced Low Alloy Steel

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***Abstract*— Slurry abrasion is a potential problem in industrial components such as slurry pumps, pipelines carrying ore and mineral slurries and extruders. The present work reports slurry abrasion response of hardfaced low alloy steel under a wide range of experimental conditions. The slurry abrasion experiments were performed using silica sand as abrasive particles. The effect of test parameter such as sliding distance, normal load, slurry concentration and particle size of abrasive medium on a slurry abrasion behaviors of hard faced alloy steel was investigated. The slurry abrasion volume loss increased with sliding distance, normal load, slurry concentration and particle size of abrasive medium. The results of the investigation suggest that particle size and slurry concentration had relatively stronger effect on wear loss as compared to that of normal load. Scanning Electron Microscopy studies revealed different morphology of the worn surfaces which was attributed to different slurry abrasion test condition.**

***Index Terms*— Metal, Steel, Slurry, wear, abrasion, cutting.**

I. Introduction

The phenomenon of wear is not only responsible for material removal but also leads to premature failure of engineering components. The monetary loss due to wear also includes cost involved in replacement and downtime cost. Abrasive wear is the most common mode of failure in industrial applications, near about 50% occurs due to this wear of total wear. Cost due to abrasive wear has been estimated to fall within range of 2-4 % of the gross national product for all nations. Abrasive wear generally occurs while transport of abrasive slurries encountered in industrial and specially mining applications .Wear by slurry abrasion occurs in extruders, slurry pumps, and pipes carrying slurry of minerals and ores in mineral processing industries. The wear life of components used under slurry abrasion conditions is governed by the process parameters, properties of abrasive particles in slurry and material properties. [1-4]. Steels and cast irons are widely used for improving wear life of engineering components under abrasive wear situations. The abrasive wear properties of carbon steels by way of change in hardness and microstructure by heat treatment have been investigated in the past by many researchers. The quenched and tempered carbon steel with martensitic microstructure showed 1.5–2.0 times better slurry abrasion resistance as compared to pearlitic microstructure (5). The abrasion resistance of steels with martensitic microstructure was also influenced by volume fraction of martensite, its carbon content, its morphology and tempering temperature (6-10). It was also observed that the slurry abrasion wear volume loss exhibited an increasing trend with increasing severity of test parameters [10].

The abrasive wear performance of surface coatings was evaluated by many researchers. N. Sari [11] observed that nitriding and boronizing offered no significant advantage to abrasion resistance as compared to HVOF or flame sprayed composite coating of Ni-Cr-B-Si. The abrasive wear performance of boronized 1010 steel was comparable to those of D2 and 304 stainless steels, whereas boronized 1040 steel exhibited superior wear performance, as reported by E.Atik [12]. They concluded that conventional nitriding and carburizing treatments were not as effective as that of boronozing. H.Dong and co-workers [13] found that sprayed coating like WC-Co,Mo,Cr-Ni provided better slurry abrasion resistance when compared to carbon steel and anodized and electroless Ni plating did not provide any substantial improvement in the performance. H.Ageorges and co-workers [14] found that 53 % Cr_2O_3-47% stainless steel coating exhibited best slurry abrasion resistance, which was attributed to the excellent cohesion of the coating.

In contrast, pure Cr_2O_3 coating showed poor slurry abrasion resistance. J.Knuuttila [15] reported that plasma sprayed alumina coatings showed three times and twenty times better slurry abrasion resistance than Cr_2O_3 coatings and stainless steel, respectively. Z.Ding and coworkers [16] observed brittle fracture, thermal cracking and chipping in ceramic nozzles. Stainless steel nozzles exhibited plastic deformation and ploughing and micro cutting were predominant mechanisms of material removal.

Hard facing by welding is a one of the economic method to improve abrasion resistance of engineering components. A little amount of data is available on slurry abrasion behaviour of weld deposited alloy steels, in particular with bainitic-martenstic microstructure. The present work reports slurry abrasion response of hardfaced low alloy steel with bainitic-martensitic microstructure under a wide range of experimental conditions. The slurry abrasion experiments were performed using silica sand as abrasive particles. The effect of test

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parameter such as sliding distance, normal load, slurry concentration and particle size of abrasive medium on a slurry abrasion behaviors of hard faced steel was investigated. Scanning Electron Microscopy studies were carried out to study morphology of abraded surfaces.

II. EXPERIMENTAL

A. Material

The material used for the slurry abrasion test was low alloy steel which was deposited by manual metal arc (MMA) welding on mild steel (0.19 % Carbon) plate with dimension of 200 x 200 mm x 10 mm The consumable used for deposition was in the form of electrode with diameter of 3.15 mm. The welding parameters were; voltage – 22 V and current – 120 A (direct current). An overlay of 4mm was deposited using welding electrode. The specimens for chemical analysis, hardness, metallographic studies and slurry abrasion testing were derived from the weld deposited plate, ground and polished as per standard metallographic practice. The chemical composition and hardness of the wed deposited surface and is given in Table1. The polished and etched specimen of weld deposited alloy steel was observed under scanning electron microscope. The microstructure of deposited surface is shown in Fig. 1 which shows bainite and martensite

B. Slurry Abrasion Wear Testing

The slurry abrasion wear tests were performed using slurry abrasion test apparatus (Ducom make, India) using silica sand abrasive (hardness = 1000–1100 HV) particles with different particle size as shown in Fig. 3(a–d). The abrasive particles were having angular (53-73 µm), irregular (125-150 µm), irregular to angular (250-300 µm) and rounded to irregular (300-425 µm) shape. The description of the apparatus can be found elsewhere (10). A schematic diagram of the slurry abrasion test apparatus is shown in Fig.3.

The specimens for slurry abrasion testing were rectangular blocks measuring 57.2 mm (length) X 25.4 mm (width) x 9.42 mm (thickness). The specimens for abrasion testing were polished with successive silicon carbide papers followed by polishing with alumina slurry and cleaned with ethyl alcohol and then weighed using a digital electronic balance to the accuracy of 0.1 mg.

After the test, specimens were cleaned with dry compressed air followed by cleaning with ethyl alcohol and then weighed. The loss in mass (g) was calculated as the difference of initial and final weight of the specimen. In addition, wear volume loss was also determined. The slurry abrasion experiments were carried out to study the effect of load (35,70,95 and 120 N), sliding distance by varying total revolutions of the wheel (500,1000,1500 and 2000), slurry concentration % (27.07, 54.14, 81.22 and 99,52) and particle size (53-73, 125-150, 250-300 and 300-425 µm on slurry abrasion loss.

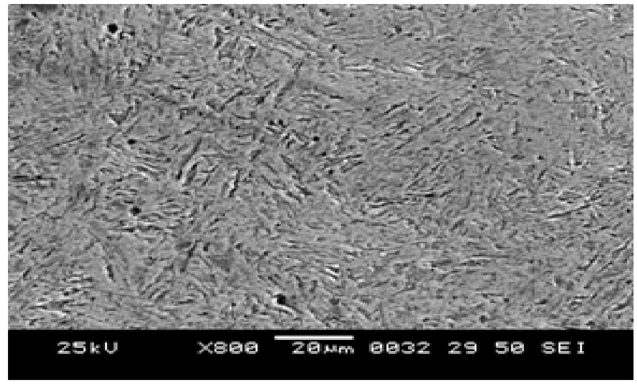

Fig 1. Microstructure of weld deposited alloy steel surface

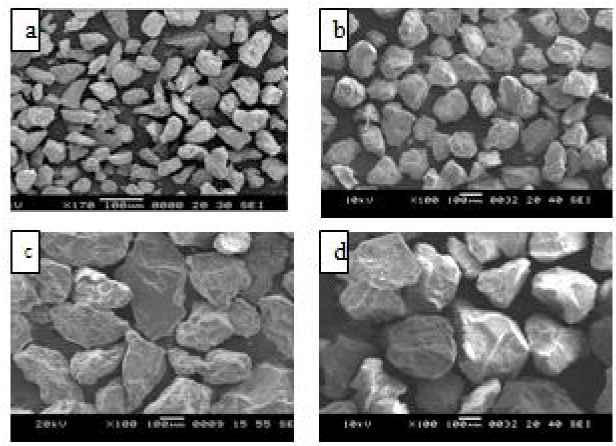

Fig 2. (a-d) SEM photographs of silica sand particles (a) 53-73 µm (b) 125-150 µm (c) 250-300µm and (d) 300-425 µm

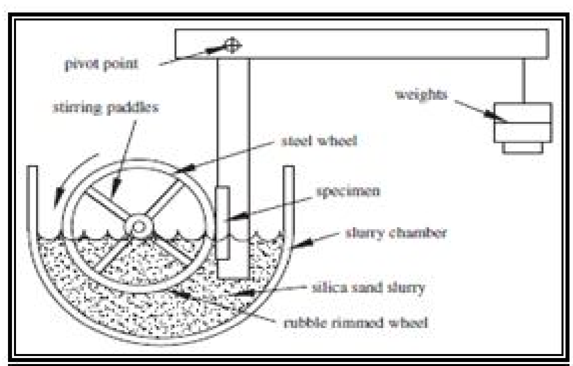

Fig 3. Schematic diagram of slurry abrasion tester

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TABLE I. CHEMICAL COMPOSITION OF WELD DEPOSITED ALLOY STEEL

Element	C	Si	Mn	Cr	S	P	Mo	Ni
Wt. %	0.16	0.6	1.0	4.1	0.02	0.02	1.96	0.9
Hardness	Bulk hardness – 42.12 HRc ; Microhardness - 481.35 $HV_{0.1}$							

III. RESULTS & DISCUSSION

The results of the present are shown in Fig.4 (a-d). The data points were fitted by best fit line in Fig.4 (a-c) and by parabola in Fig.4 d. The regression coefficients were in the range of 0.9625 – 0.9993. It can be observed from Fig. 4 (a-c) that slurry abrasion volume loss exhibited an increasing trend with sliding distance, slurry concentration and load however the magnitude of increase was different in each case. The slurry abrasion volume loss increased linearly and almost by four times with sliding distance.The slurry abrasion volume loss increased nearly fifteen times for more than 3.5 times increase in slurry concentration.

The magnitude of increase was initially more than six times for two fold increase in slurry concentration, whereas for further increase in slurry concentration by volume loss increased more than two times. An increase in normal load from 35 N to 125 N resulted in slurry abrasion volume loss to increase by more than two times. The effect of silica sand particle size was quite different from other experimental parameters. The slurry abrasion volume loss increased significantly with increase in silica sand particle size. The slurry abrasion volume loss increased more than twenty two times for more than six times increase in particle size, as shown in Fig. 4(d). The slurry abrasion volume loss exhibited power law dependence on particle size which is expressed as,

$$V = kd^{m} \quad (1)$$

where V is the volume loss in mm^3, k is the constant and d is the average particle size of silica sand. The value of k was 0.0032 and the exponent m was 1.8438. Thus particle size and slurry concentration had relatively stronger effect on slurry abrasion volume loss. Similar observations were reported in the past [11]. It is difficult to compare the results of the present work with those of earlier investigations due to different test conditions, material properties and abrasive particle properties. [7,9,10,14-16].

Figs.5 (a-c) shows morphology of worn out surfaces after slurry abrasion under different test conditions.The parallel grooves caused by silica sand particles can be observed on the abraded surface. The grooves were relatively deeper and wider at higher loads as compared to lower load as seen in Fig.5 a and b. The increase in slurry abrasion volume loss with increased load can be attributed to increased depth of cut by abrasive particles. With increase in slurry concentration the slurry abrasion loss increased significantly. Although an increase in number of abrasive particles resulted in greater wear loss, due to particle interaction the rate of increase was relatively less at higher slurry concentrations as can be observed in Fig.4(b). The morphology of abraded surface at finest particle size is shown in Fig. 5(c), which reveals relatively smooth surface, narrower and shallower grooves, leading to lower abrasion loss.With coarser abrasive particles, the damage zone sizes was significantly more as compared with finer particles hence slurry abrasion volume loss increased more than twenty times when the silica sand size was increased from 53-73 µm to 300-425 µm. The significant increase in slurry volume loss with increase in particle size can be attributed to particle size effect [17]. The mechanism of material was ploughing under benign slurry abrasion conditions and micro-cutting mechanism predominated at severe slurry abrasion conditions.

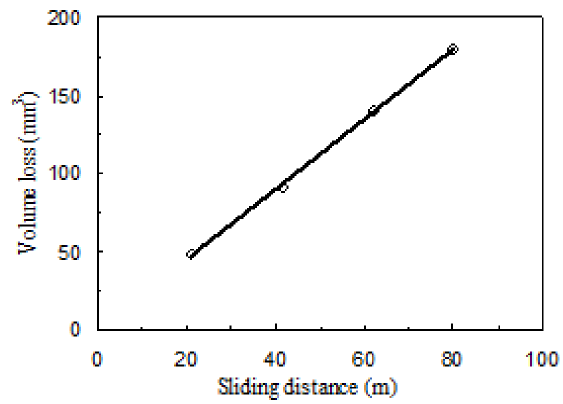
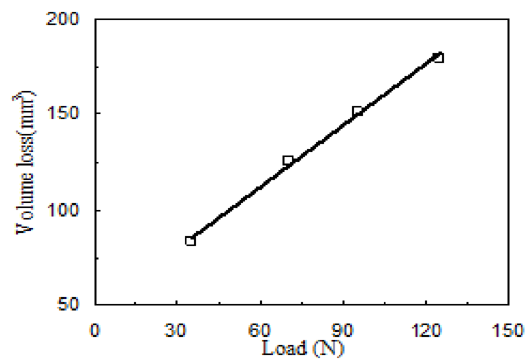
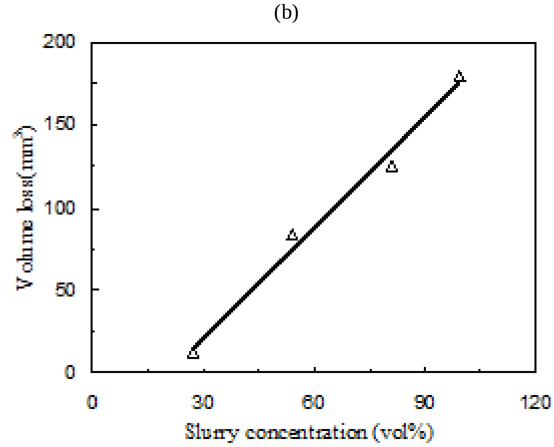


Fig 4. (a) Slurry abrasion volume loss of hardfaced alloy steel vs sliding distrance



(b)



(c)

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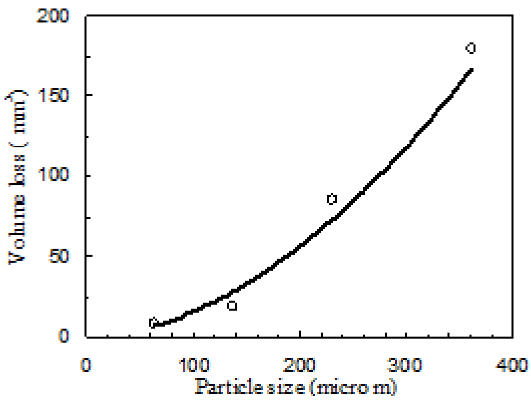
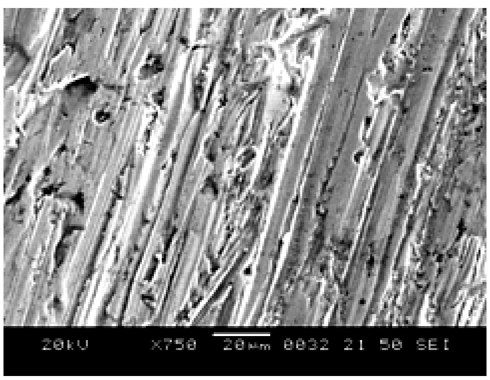


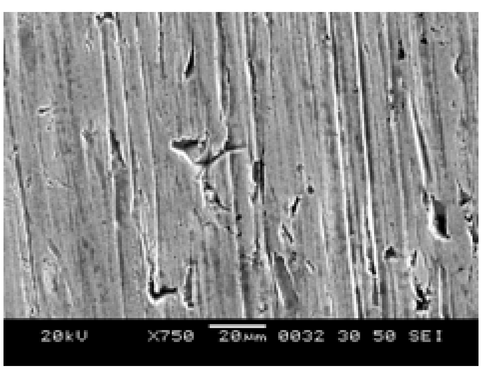
(d)

Fig.4 (b-d) Slurry abrasion volume loss of hardfaced alloy steel vs. (b) load (c) slurry concentration and(d) particle size of silica sand

The results if the present investigations shall be useful in material selection for slurry abrasion applications. The study of interactive effect of operating parameters in relation to abrasives with different hardness is expected to provide comprehensive understanding of material properties required under different slurry abrasive wear situations.



(a)



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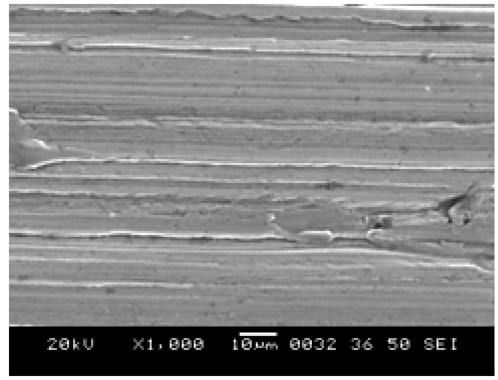

(c)

Fig 5. (a-c) SEM photographs of abraded surface (a) 125 N load (b) 70 N load (c) 27.07 % Slurry concentration

CONCLUSIONS

The slurry abrasion volume loss of hard faced alloy steel exhibited linear relationship with sliding distance. The effect of slurry concentration on slurry abrasion volume loss was more pronounced than the effect of normal load. The slurry abrasion volume loss increased significantly with increase in particle size of silica sand. The magnitude of increase in slurry abrasion volume loss was strongly dependent on test conditions. Scanning Electron Microscope observations revealed different morphology of the worn surfaces which was attributed to different slurry abrasion test conditions. The important mechanisms of material removal were ploughing and cutting. In the present investigation no attempt is made to assess the effect of abrasive particle fracture on slurry abrasion loss of hardfaced alloy steel. The further work is in progress in this direction.

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